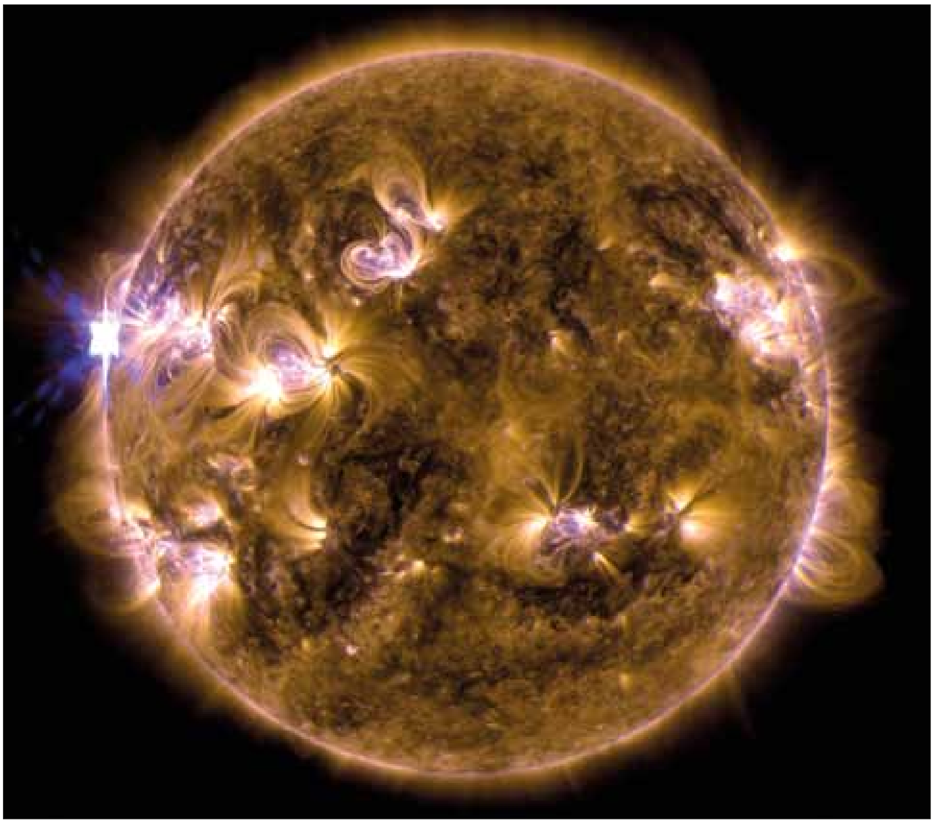
Recruiting flare hunters for citizen science

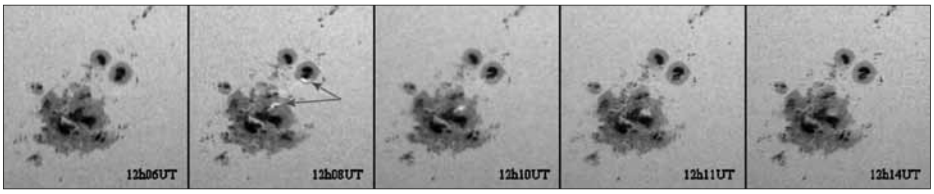
Lyndsay Fletcher, **Arkadiusz Berlicki**, **Arun Kumar Awasthi** and **Dominik Gronkiewicz** describe how they established F-HUNTERS, a pro–am solar flare observing campaign.

The contributions of amateur scientists to astronomy and geophysics research are wide-ranging, from the citizen scientists who help with galaxy classification or identify meteors from their radio signatures, to the supernova hunters and variable-star observers providing the vital day-to-day monitoring that is now a lower priority for professional observatories. In the F-HUNTERS campaign, we set out to involve the large community of amateur solar observers in joint observations, providing both context and complementary data to the results obtained by professional ground- and space-based solar telescopes.

The F in the name stands for flare; solar flares are sudden, unpredictable and transient events in the atmosphere of the Sun. They affect all parts of the solar atmosphere in the flaring active region – the photosphere, chromosphere and corona. During a flare, energy that was stored in stressed coronal magnetic fields is released (a process facilitated by magnetic reconnection) and converted into other forms. The solar plasma is heated strongly, and electrons, protons and heavier ions are accelerated. A flare produces radiation across the entire electromagnetic spectrum, from radio waves to gamma rays. Though flares look very dramatic when observed in high-energy radiation – e.g. the extreme UV or X-ray part of the spectrum showing hot coronal flare loops (figure 1) – the flare spectrum peaks around optical wavelengths, and the majority of flare radiation originates from the chromosphere and photosphere. This part of the spectrum is rich in diagnostic lines and continua, such as the hydrogen alpha line. Images in Hα show finely structured flare "ribbons" that spread across the chromosphere as the flare proceeds, as well as surges, sprays and eruptions (figure 6).



1 An X-class white-light solar flare erupting on the left-hand side of the Sun in this composite image using ultraviolet light at wavelengths of 131 Å and 171 Å taken by Solar Dynamics Orbiter. (NASA/SDO)

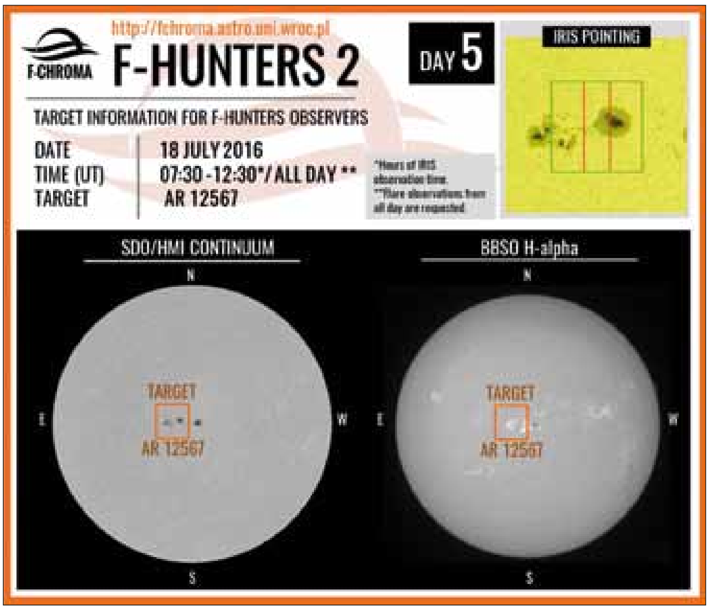


2 A sequence of images taken by observer Thierry Legault showing the transient sources of a major white-light flare on 28 October 2003. (© T Legault, used with permission. http://www.astrophoto.fr)

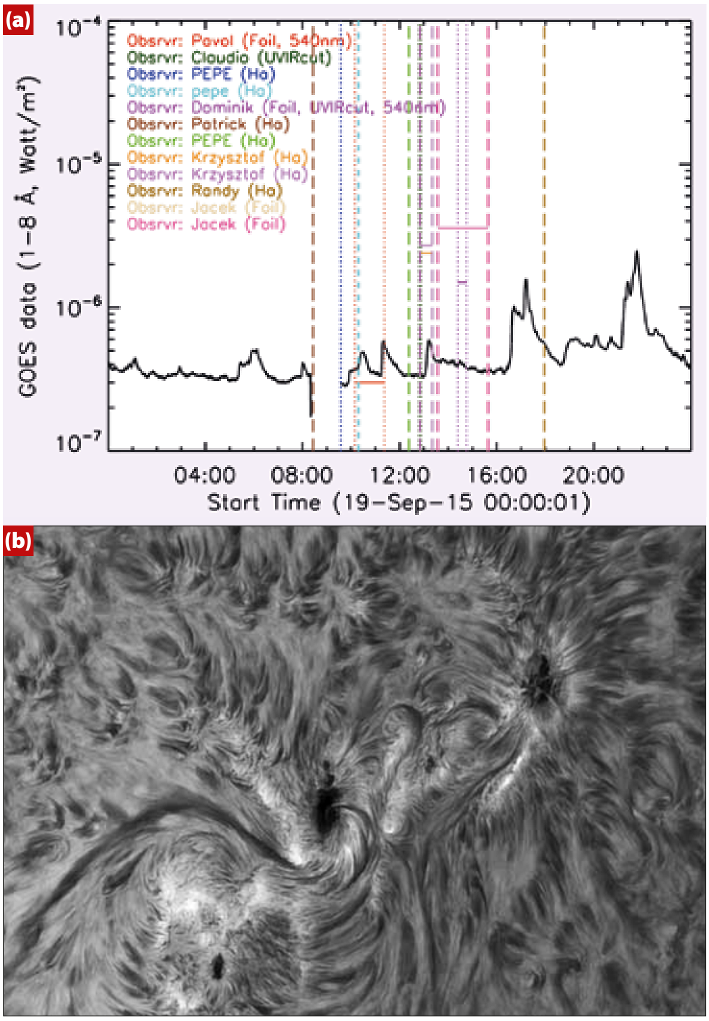
White-light events

Ground-based observations furnish us with important information about flare evolution, and about conditions in the flaring chromosphere. However, professional high-resolution ground-based telescopes tend to emphasize solar spectroscopy; basic imaging of the Sun, particularly in the optical continuum (i.e. white light) often gets neglected. The first recorded flare observation, the Carrington Flare of 1859, was made in white light with a small refractor, but white-light flare observations are still rare. Amateur solar observers have access to high-quality equipment and regularly produce images of startling quality, typically with a large field of view giving a higher probability of catching a flare (figure 2), and at a higher resolution than that of the full-disc flare patrol spectroheliographs making routine observations.

F-HUNTERS is part of the EC-funded F-CHROMA project investigating the physics of the solar chromosphere during flares. The solar chromosphere, lying between the photosphere and the corona, is complex, dynamic and highly structured, with temperature, density and ionization fraction changing by orders of magnitude over its approximately 2000 km thickness.



3 An example of the information disseminated daily to amateurs, showing the target region in optical and Hα, and also the location of the fields of view of participating space-based observatories.



4 (Top) The Sun's soft X-ray lightcurve for 19 September 2015, superimposed with the observer's name and the filter used. (Bottom) An Hα image captured in the decay of a C2 flare at around 18:00 UT by observer Randy Shivak. (© R Shivak)

By probing the chromospheric flare radiation enhancements, we seek to learn about energy deposition and dissipation. However, the solar flare spectral distribution around the optical peak is surprisingly ill-constrained, possibly because observational attention has shifted to other parts of the spectrum where the contrast against the solar disc is higher and the magnetic evolution more easily inferred. This is in marked contrast to stellar flares, where the optical spectrum and its evolution are frequently measured.

Collecting scientifically useful data requires more information than might typically be recorded by amateur observers, so we prepared a set of tutorial web pages listing some simple rules and techniques to add scientific value to the images captured. The pages were written by one of us (DG) who is also a keen amateur observer familiar with the types of instruments, cameras and software used by the amateur community (see http://fchroma.astro.uni.wroc.pl/index.php/observing-guide.html).

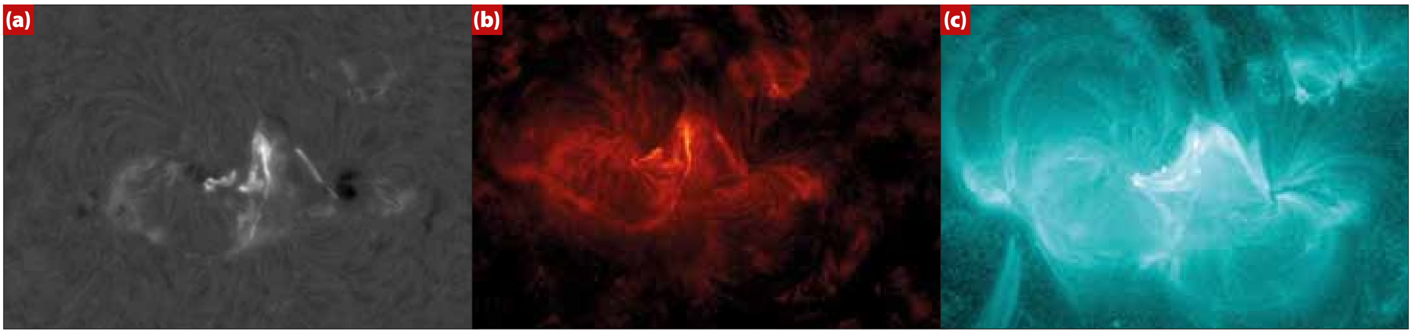
Our "three rules for collecting solar data":

- Keep time. To trace the evolution of a flare, a series of images is necessary, with accurate timestamps that will make possible joint analysis with data from other sources, including satellites.
- Calibrate. Instrumental effects need to be corrected for, and it is not difficult to make the dark current and flat field observations to do this.
- Stay raw. Digital enhancements such as sharpening, denoising and contrast adjustments make for stunning images but are subjective and destroy the raw signal.

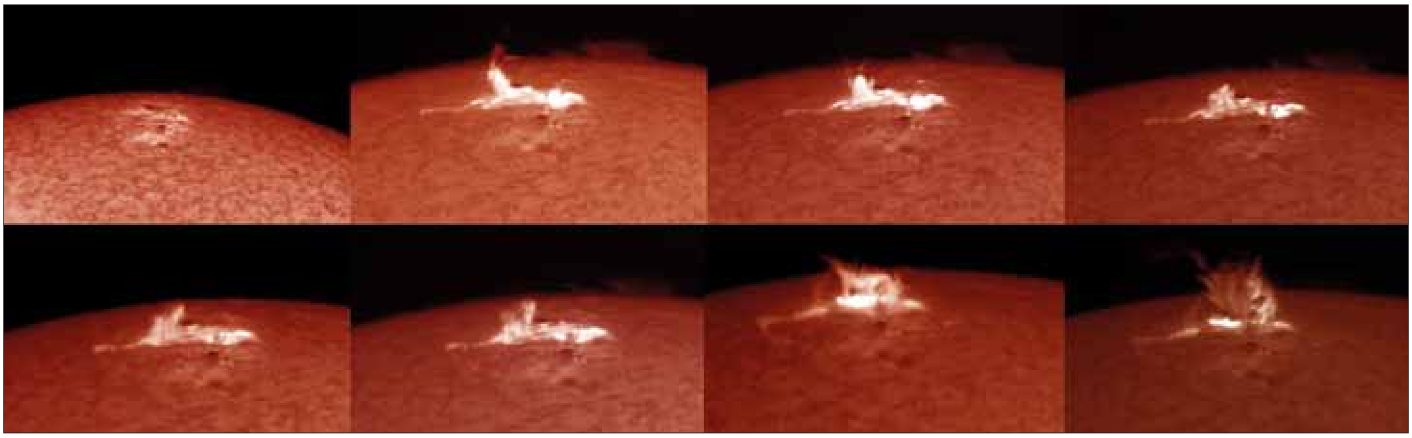
Each of these rules was described in detail in the web pages, together with advice on how to make sure the clock in a DSLR camera is synchronized, how to record times in UT, and how to make bias and dark frames and flat fields. The descriptions used examples that many amateurs would be familiar with. However, there is a great range of experience and expertise among amateur solar observers. As our primary aim was to engage the widest possible group in our campaign, we suggested a range of observing techniques including everything from the camera obscura or pinhole principle used by Kepler to observe sunspots in a darkened room in his house, through the projection method, to the use of tunable filters and planetary cameras.

Communication and coordination

We organized F-HUNTERS into two campaigns of around a week each, running in September 2015 and July 2016. These coincided with periods when we had obtained observing time on professional ground-based telescopes (for example the Dunn Solar Telescope at the US National Solar Observatory in 2015, and the Swedish Solar Telescope in 2016), with support also from space-based instruments, in particular the IRIS satellite. Coordination is key in these efforts and professional observatories have well-rehearsed processes for identifying and disseminating the solar targets for a given science goal. Our science goal being flares, targets were always the largest or the most flare-productive sunspot group on the Sun. Professional observatories use two main co-ordinate systems: heliographic latitude and longitude, or arcseconds east–west/north–south with respect to Sun centre. Amateur observers, depending on their equipment and set-up, may not be able to adopt this system easily. Therefore we produced images in the optical and Hα, showing the target for each day's observation (figure 3). Targets for the next day were sent out daily by social media and the main page of the F-HUNTERS project. Amateurs



5 A C4.4 flare on 18 July 2016 captured during the main impulsive energy-release phase. (a) Shown in Hα (© Pepe Manteca). (b) As seen in the He II 304 Å filter of the AIA instrument on the Solar Dynamics Observatory. (c) In the 131 Å filter of AIA, predominantly showing plasma at 10 million K in the central flare region.



6 Hα images of AR12567 during the M5.0 flare on 23 July 2016. The images correspond to post-impulsive phase activity from 04:15–05:32 UT. (© Alfred Tan)

who had data that they wished to share were requested to put it online, and provide us with a link and details via a web form.

The campaigns

The first campaign, 19–27 September 2015, coincided with a period of relatively low solar activity overall, but nonetheless 120 amateurs registered with the campaign and we received data from participants from nine countries. Some excellent observations were captured at the beginning and the end of the week.

The image quality that can be achieved by amateur observers is clear in figure 4b, which shows the late decay phase of a small C-class flare, obtained by experienced solar observer Randy Shivak. The central region of this event was also observed by the IRIS spacecraft, though it stopped observations less than two minutes before figure 4b was taken – illustrating the difficulty, familiar to solar observers, of getting both time and space right in coordinated observations!

The second campaign, 14–23 July 2016, ran during a period of fairly high solar activity. Amateur observations were very successful, with around 150 observers signed up to the campaign. This time we made a special appeal for time-series data, which can be challenging for amateur observers because of the storage requirements. We received some excellent series of images in Hα line centre and off-band, and also in the optical continuum. The high quality of these observations can again be seen in the Hα image of a C4.4 flare on 18 July 2016, one of a time-series made by observer Pepe Manteca (figure 5a). This is shown in comparison to an image from the Atmospheric Imager Assembly on the Solar Dynamics Observatory made within a few seconds (figure 5b). The Hα image very clearly shows the finely structured flare ribbons penetrating the sunspot umbra. This event was also observed by the IRIS spacecraft, which imaged the left-most flare ribbon but missed capturing it spectroscopically by just a few seconds of arc. The Swedish Solar Telescope in the Canary Islands also captured it in part, at extremely high spatial and spectral resolution.

"Many of the images recorded by amateurs rival professional observatories"

Many of the image series recorded by amateurs in this campaign are of a quality rivaling professional observatories operating in the same part of the spectrum. In figure 6, a spectacular set of images of sprays and surges during an M5.0 flare made by observer Alfred Tan shows also the solar chromospheric network and fibril structure in absorption. Such high-quality images are suitable for more rigorous analysis, particularly if intensity calibrations can be carried out. This can be done in principle using the known properties of the quiet solar chromosphere in the filters used.

These two campaigns attracted significant interest from the amateur community and we are grateful also to the professional telescopes that took part so enthusiastically. The amateur community provided some images that are suitable for scientific analysis, though there is room for improvement in the organization of future campaigns to ensure that we get the best kind of data. For example, our appeal for data to be provided in a raw and uncompressed file format met with mixed success – we received quite a lot of jpeg images which suffer from lossy compression, though these are still useful for morphological comparisons. Also timestamps proved to be an issue, with some observers attaching their local image times rather than UT. Rough corrections to UT can be made straightforwardly, but it is not so easy to account for the accuracy of local clock settings on scales of seconds, which can be critical for rapidly evolving phenomena such as flares. Through dialogue with the community of amateurs we can motivate and explain such requirements, so that amateur observations can be further integrated into professional solar research. ●

AUTHORS

Lyndsay Fletcher, School of Physics & Astronomy, University of Glasgow, UK. **Arkadiusz Berlicki**, **Arun Kumar Awasthi**, **Dominik Gronkiewicz**, Astronomical Institute, University of Wrocław, Poland.

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